

WHAT IS CLAIMED IS:

1. An estimating apparatus for a secondary cell, comprising:

5 a current detecting section that detects a current (I) charged into and discharged from the secondary cell;

a voltage detecting section that detects a terminal voltage (V) across the secondary cell;

10 a parameter estimating section that integrally estimates all parameters (θ) at one time in at least one of the following equations (1) and (2) with the measured current (I) and terminal voltage (V) inputted into an adaptive digital filter using a cell
15 model described in a corresponding one of the following equations (1) and (2) whose parameters are estimated;

an open-circuit voltage calculating section that calculates an open-circuit voltage (V_o) using
20 the current (I), the terminal voltage (V), and the parameter estimated values (θ);

an input enabling power estimating section that estimates an input enabling power (P_{in}) of the secondary cell on the basis of the parameter
25 estimated values (θ) and open-circuit voltage (V_o);
and

an output enabling power estimating section that estimates an output enabling power (P_{out}) of the secondary cell on the basis of the parameter
30 estimated values and the open-circuit voltage (V_o),
the equation (1) being

$$V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{C(s)} \cdot V_o \quad \dots (1), \text{ wherein}$$

$$A(s) = \sum_{k=0}^n a_k \cdot s^k, \quad B(s) = \sum_{k=0}^n b_k \cdot s^k, \quad C(s) = \sum_{k=0}^n c_k \cdot s^k, \quad s$$

denotes a Laplace transform operator, $A(s)$, $B(s)$, and $C(s)$ denote each poly-nominal of s (n denotes degrees), $a_1 \neq 0$, $b_1 \neq 0$, and $c_1 \neq 0$ and the equation

5 (2) being $V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{A(s)} \cdot V_o \dots (2)$, wherein

$$A(s) = \sum_{k=0}^n a_k \cdot s^k \quad \text{and} \quad B(s) = \sum_{k=0}^n b_k \cdot s^k.$$

2. An estimating apparatus for a secondary cell as claimed in claim 1, wherein the adaptive digital
10 filter uses the cell model described in the equation (1) and the parameter estimating section integrally estimates all of the parameters (θ) in the equation (1) at one time and wherein, in a case where the terminal voltage of the secondary cell immediately
15 before the secondary cell becomes a predetermined excessive charge is assumed to be a maximum enabling voltage (V_{\max}) and the terminal voltage of the secondary cell immediately before the secondary cell becomes a predetermined excessive discharge is
20 assumed to be a minimum enabling voltage (V_{\min}), the input enabling power estimating section estimates the input enabling power (P_{in}) of the secondary cell on the basis of the parameter estimated values (θ), the open-circuit voltage (V_o), and the maximum enabling
25 voltage (V_{\max}) and the output enabling power estimating section estimates the output enabling power (P_{out}) of the secondary cell on the basis of the parameter estimated values (θ), the open-circuit voltage (V_o), and the minimum enabling voltage (V_{\min}).

3. An estimating apparatus for a secondary cell as claimed in claim 2, wherein the input enabling power estimating section calculates $V_o/C(s)$ from the
5 parameter estimated values and the open-circuit voltage (V_o) and the input enabling power estimating section estimates the input enabling power (P_{in}) of the secondary cell on the basis of one of the open-circuit voltage (V_o) and the calculated ($V_o/C(s)$)
10 whose value is nearer to the maximum enabling voltage (V_{max}), the parameter estimated values (θ), and the minimum enabling voltage (V_{min}).

4. An estimating apparatus for a secondary cell as
15 claimed in claim 2, wherein the output enabling power estimating section calculates $V_o/C(s)$ from the parameter estimated values (θ) and the open-circuit voltage (V_o) and the output enabling power estimating section estimates the output enabling power (P_{out}) of
20 the secondary cell on the basis of one of the open-circuit voltage (V_o) and the calculated $V_o/C(s)$ whose value is nearer to the minimum enabling voltage (V_{min}), the parameter estimated values (θ), and the maximum output enabling voltage (V_{max}).

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5. An estimating apparatus for a secondary cell as claimed in claim 2, wherein the input enabling power estimating section calculates $V_o/C(s)$ from the parameter estimated values (θ) and the open-circuit
30 voltage (V_o) and estimates the input enabling power (P_{in}) of the secondary cell on the basis of one of the open-circuit voltage (V_o) and the calculated $V_o/C(s)$ whose value is nearer to the maximum enabling

voltage (V_{\max}), the parameter estimated values (θ), and the maximum enabling voltage (V_{\max}) and wherein the output enabling power estimating section estimates the output enabling power (P_{out}) of the secondary cell on the basis of one of the open-circuit voltage (V_0) and the calculated $V_0/C(s)$ whose value is nearer to the minimum enabling voltage (V_{\min}).

6. An estimating apparatus for a secondary cell as claimed in claim 5, wherein the input enabling power estimating section estimates the input enabling power (P_{in}) using the following equation:

$$\left. \begin{aligned} P_{\text{in}} &= I_{\text{in_max}} \cdot V_{\max} \\ &= \frac{V_{\max} - V_0}{e} \cdot V_{\max} \end{aligned} \right]$$

, wherein $I_{\text{in_max}}$ denotes a maximum input current to the secondary cell calculated from the following equation: $V = K \cdot I + V_0$, wherein e is substituted for K , V_{\max} is substituted into V , $I_{\text{in_max}}$ is substituted for I , and $V_0(k)$ is substituted for V_0 , $V_0(k) = \Delta V_0(k) + V_{\text{in1}}$, wherein $V_0(k)$ is substituted for $\Delta V_0(k)$ and V_{in1} denotes an initial value of the terminal voltage when no current from the secondary cell is caused to flow, and $e = K + h \cdot T_1 \doteq K$, wherein K denotes one of the parameter estimated values (θ) which corresponds to an internal resistance of the secondary cell, when the calculated open-circuit voltage $V_0(k)$ at a time point of k is equal to or higher than an apparent open-circuit voltage $V'_0(k)$ and estimates the input enabling power (P_{in}) using the following equation:

$$\begin{aligned}
 P_{in} &= I_{in_max} \cdot V_{max} \\
 &= \frac{V_{max} - V_o'}{e} \cdot V_{max} \\
 &= \frac{V_{max} - \frac{V_o}{b \cdot s + 1}}{e} \cdot V_{max}
 \end{aligned}
 \left. \vphantom{\begin{aligned} P_{in} &= I_{in_max} \cdot V_{max} \\ &= \frac{V_{max} - V_o'}{e} \cdot V_{max} \\ &= \frac{V_{max} - \frac{V_o}{b \cdot s + 1}}{e} \cdot V_{max} \end{aligned}} \right]$$

,wherein $b = T_3 + T_1 \div T_3$ and T_1 and T_3 denotes time constants, when the calculated open-circuit voltage $V_o(k)$ at the time point of k is lower than the apparent open-circuit voltage $V_o'(k)$, wherein $V_o(k) = \Delta V_o(k) + V_{ini}$, wherein $V_o(k) = \Delta V_o(k)$, when the calculated open-circuit voltage $V_o(k)$ at the time point of k is lower than an apparent open-circuit voltage $V_o'(k)$.

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7. An estimating apparatus for a secondary cell as claimed in claim 6, wherein the output enabling power estimating section estimates the output enabling power (P_{out}) using the following equation:

$$\begin{aligned}
 P_{out} &= |I_{out_max}| \cdot V_{min} \\
 &= \frac{V_o - V_{min}}{e} \cdot V_{min}
 \end{aligned}
 \left. \vphantom{\begin{aligned} P_{out} &= |I_{out_max}| \cdot V_{min} \\ &= \frac{V_o - V_{min}}{e} \cdot V_{min} \end{aligned}} \right]$$

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,when the calculated open-circuit voltage $V_o(k)$ at the time point of k is equal to or higher than the apparent open-circuit voltage $V_o'(k)$ and

$$\begin{aligned}
 P_{out} &= |I_{out_max}| \cdot V_{min} \\
 &= \frac{V_o' - V_{min}}{e} \cdot V_{min} \\
 &= \frac{\frac{V_o}{b \cdot s + 1} - V_{min}}{e} \cdot V_{min}
 \end{aligned}
 \left. \vphantom{\begin{aligned} P_{out} &= |I_{out_max}| \cdot V_{min} \\ &= \frac{V_o' - V_{min}}{e} \cdot V_{min} \\ &= \frac{\frac{V_o}{b \cdot s + 1} - V_{min}}{e} \cdot V_{min} \end{aligned}} \right]$$

, when the calculated open-circuit voltage ($V_o(k)$) at the time point of k is lower than the apparent open-circuit voltage ($V_o'(k)$) at the time point of k .

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8. An estimating apparatus for a secondary cell as claimed in claim 7, wherein

$$\Delta V_o' = \frac{1}{T_3 \cdot s + 1} \cdot \Delta V_o \approx \frac{1}{b \cdot s + 1} \cdot \Delta V_o \text{ corresponds to } V_o/C(s) \text{ and}$$

$$\text{wherein } \Delta V_o = \frac{(T_1 \cdot s + 1)}{G_2(s)} \cdot V_o = a \cdot V_6 + b \cdot V_5 + V_4 - c \cdot I_6 - d \cdot I_5 - e \cdot I_4,$$

10 and wherein $a = T_1 \cdot T_3$, $b = T_1 + T_3$, $c = K \cdot T_2 - T_3$, $d = K \cdot (T_2 + T_3)$, $e = K + h \cdot T_1 \approx K$, $G_2(s)$ denotes a low pass filter, T_1 , T_2 , and T_3 denote each time constant, and

$$\begin{aligned}
 I_4 &= \frac{1}{G_2(s)} \cdot I & V_4 &= \frac{1}{G_2(s)} \cdot V \\
 I_5 &= \frac{s}{G_2(s)} \cdot I & V_5 &= \frac{s}{G_2(s)} \cdot V & \frac{1}{G_2(s)} &= \frac{1}{p_2 \cdot s + 1} \cdot \frac{1}{T_1 \cdot s + 1} \\
 I_6 &= \frac{s^2}{G_2(s)} \cdot I & V_6 &= \frac{s^2}{G_2(s)} \cdot V
 \end{aligned}
 \left. \vphantom{\begin{aligned} I_4 &= \frac{1}{G_2(s)} \cdot I & V_4 &= \frac{1}{G_2(s)} \cdot V \\ I_5 &= \frac{s}{G_2(s)} \cdot I & V_5 &= \frac{s}{G_2(s)} \cdot V & \frac{1}{G_2(s)} &= \frac{1}{p_2 \cdot s + 1} \cdot \frac{1}{T_1 \cdot s + 1} \\ I_6 &= \frac{s^2}{G_2(s)} \cdot I & V_6 &= \frac{s^2}{G_2(s)} \cdot V \end{aligned}} \right] .$$

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9. An estimating apparatus for a secondary cell as claimed in claim 8, wherein the open-circuit voltage ($V_o(k)$) at the time point of k is estimated from the following equation:

$$\frac{(T_1 \cdot s + 1)}{G_2(s)} \cdot V_0 = \frac{1}{G_2(s)} (a \cdot s^2 + b \cdot s + 1) \cdot V - \frac{1}{G_2(s)} (c \cdot s^2 + d \cdot s + K) \cdot I.$$

10. An estimating apparatus for a secondary cell as claimed in claim 9, wherein the parameter
5 estimating section integrally estimates the parameters used in the equation (1) at one time as follows:

$$\theta = \begin{bmatrix} -a \\ -b \\ c \\ d \\ e \\ f \end{bmatrix}$$

wherein $f = h$ and h denotes a variable efficiency
10 derived from the following equation: $V_0 = \frac{h}{s} \cdot I.$

11. An estimating apparatus for a secondary cell as claimed in claim 10, wherein the equation (1) is arranged in an equivalent circuit model expressed as:

$$15 \quad V = \frac{K \cdot (T_2 \cdot s + 1)}{T_1 \cdot s + 1} \cdot I + \frac{1}{T_3 \cdot s + 1} \cdot V_0.$$

12. An estimating apparatus for a secondary cell as claimed in claim 1, wherein the adaptive digital filter uses the cell model described in the equation
20 (2) and the parameter estimating section integrally estimates all parameters (θ) in the equation (2) at one time.

13. An estimating apparatus for a secondary cell
25 as claimed in claim 12, wherein, in a case where the terminal voltage of the secondary cell immediately

before the secondary cell becomes a predetermined excessive charge is assumed to be a maximum enabling voltage (V_{\max}) and the terminal voltage of the secondary cell immediately before the secondary cell becomes a predetermined excessive discharge is assumed to be a minimum enabling voltage (V_{\min}), the input enabling power estimating section estimates the input enabling power (P_{in}) of the secondary cell on the basis of the parameter estimated values (θ) and the open-circuit voltage (V_o), and the maximum enabling voltage (V_{\max}) and the output enabling power estimating section estimates the output enabling power (P_{out}) of the secondary cell on the basis of the parameter estimated values (θ), the open-circuit voltage (V_o), and the minimum enabling voltage (V_{\min}).

14. An estimating apparatus for a secondary cell as claimed in claim 13, wherein the input enabling power estimating section estimates the input enabling power (P_{in}) using the following equation:

$$\left. \begin{aligned} P_{in} &= I_{in_max} \cdot V_{\max} \\ &= \frac{V_{\max} - V_o}{K} \cdot V_{\max} \end{aligned} \right]$$

, wherein I_{in_max} denotes a maximum input current calculated from an equation: $V = K \cdot I + V_o$, wherein V_{\max} is substituted for V and K denotes an internal resistance of the secondary cell which corresponds to one of the parameter estimated values (θ), and I_{in_max} is substituted for I .

15. An estimating apparatus for a secondary cell as claimed in claim 14, wherein the output enabling

power estimating section estimates the output enabling power (P_{out}) as follows:

$$P_{out} = \left[\begin{aligned} &I_{out_max} \cdot V_{min} \\ &= \frac{V_0 - V_{min}}{K} \cdot V_{min} \end{aligned} \right]$$

, wherein I_{out_max} is a maximum output current

5 calculated from an equation: $V = K \cdot I + V_0$ in which V_{min} is substituted for V and I_{out_max} is substituted for I .

16. An estimating apparatus for a secondary cell
10 as claimed in claim 15, wherein the open-circuit voltage calculating section calculates the open-circuit voltage estimated value ($V_0(k)$) at a time point of k as follows: $V_0(k) = \Delta V_0(k) + V_{ini}$, wherein V_{ini} denotes an initial value of the terminal voltage
15 when no current is caused to flow into the secondary cell and $\Delta V_0(k) = \Delta V_0 = G_{lp}(s) \cdot V_0 = V_1 + T_1 \cdot V_2 - K \cdot T_2 \cdot I_2 - K \cdot I_1$, wherein

$$\left[\begin{aligned} G_{lp}(s) &= \frac{1}{(p \cdot s + 1)^3}, & V_2 &= s \cdot G_{lp}(s) \cdot V, & V_1 &= G_{lp}(s) \cdot V \\ & & I_2 &= s \cdot G_{lp}(s) \cdot I, & I_1 &= G_{lp}(s) \cdot I \end{aligned} \right]$$

, wherein $G_{lp}(s)$ denotes a low pass filter, p denotes
20 a constant determining a response characteristic of $G_{lp}(s)$, and T_1 and T_2 denote time constants of an equivalent circuit model of the secondary cell expressed in the equation (2).

25 17. An estimating apparatus for a secondary cell as claimed in claim 16, wherein the parameter estimating section integrally estimates all parameters used in the equation (2) at one time as follows:

$$\theta = \begin{bmatrix} -T_1 \\ K \cdot T_2 \\ K \\ h \end{bmatrix}$$

, wherein h denotes a variable efficiency and is derived from the following equation: $V_0 = \frac{h}{s} \cdot I$.

18. An estimating apparatus for a secondary cell as claimed in claim 16, wherein, in the equation (2), when $(T_1 \cdot s + 1)$ is substituted for $A(s)$ and $K \cdot (T_2 \cdot s + 1)$ is substituted for $B(s)$, the following equation is established:

$$V = \frac{K \cdot (T_2 \cdot s + 1)}{T_1 \cdot s + 1} \cdot I + \frac{1}{T_1 \cdot s + 1} \cdot V_0.$$

19. An estimating apparatus for a secondary cell, comprising:

current detecting means for detecting a current (I) charged into and discharged from the secondary cell;

voltage detecting means for detecting a terminal voltage (V) across the secondary cell;

parameter estimating means for integrally estimating all parameters (θ) at one time in at least one of the following equations (1) and (2) with the measured current (I) and terminal voltage (V) inputted into an adaptive digital filter using a cell model described in a corresponding one of the following equations (1) and (2) whose parameters are estimated;

open-circuit voltage calculating means for calculating an open-circuit voltage (V_0) using the

current (I), the terminal voltage (V), and the parameter estimated values (θ);

input enabling power estimating means for estimating an input enabling power (P_{in}) of the secondary cell on the basis of the parameter estimated values (θ) and open-circuit voltage (V_o); and

output power enabling power estimating means for estimating an output enabling power (P_{out}) of the secondary cell on the basis of the parameter estimated values and the open-circuit voltage (V_o), the equation (1) being

$$V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{C(s)} \cdot V_o \quad \dots (1), \text{ wherein}$$

$$A(s) = \sum_{k=0}^n a_k \cdot s^k, \quad B(s) = \sum_{k=0}^n b_k \cdot s^k, \quad C(s) = \sum_{k=0}^n c_k \cdot s^k, \quad s$$

denotes a Laplace transform operator, $A(s)$, $B(s)$, and $C(s)$ denote each poly-nominal of s (n denotes degrees), $a_1 \neq 0$, $b_1 \neq 0$, and $c_1 \neq 0$ and the equation

$$(2) \text{ being } V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{A(s)} \cdot V_o \quad \dots (2), \text{ wherein}$$

$$A(s) = \sum_{k=0}^n a_k \cdot s^k \quad \text{and} \quad B(s) = \sum_{k=0}^n b_k \cdot s^k.$$

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20. An estimating method for a secondary cell, comprising:

detecting a current (I) charged into and discharged from the secondary cell;

25 detecting a terminal voltage (V) across the secondary cell;

integrally estimating all parameters (θ) at one time in at least one of the following equations (1)

and (2) with the measured current (I) and terminal voltage (V) inputted into an adaptive digital filter using a cell model described in a corresponding one of the following equations (1) and (2) whose

5 parameters are estimated;

calculating an open-circuit voltage (V_o) using the current (I), the terminal voltage (V), and the parameter estimated values (θ);

10 estimating an input enabling power (P_{in}) of the secondary cell on the basis of the parameter estimated values (θ) and open-circuit voltage (V_o); and

estimating an output enabling power (P_{out}) of the secondary cell on the basis of the parameter estimated values and the open-circuit voltage (V_o),
15 the equation (1) being

$$V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{C(s)} \cdot V_o \quad \dots (1), \text{ wherein}$$

$$A(s) = \sum_{k=0}^n a_k \cdot s^k, \quad B(s) = \sum_{k=0}^n b_k \cdot s^k, \quad C(s) = \sum_{k=0}^n c_k \cdot s^k, \quad s$$

denotes a Laplace transform operator, $A(s)$, $B(s)$, and
20 $C(s)$ denote each poly-nominal of s (n denotes degrees), $a_1 \neq 0$, $b_1 \neq 0$, and $c_1 \neq 0$ and the equation

$$(2) \text{ being } V = \frac{B(s)}{A(s)} \cdot I + \frac{1}{A(s)} \cdot V_o \quad \dots (2), \text{ wherein}$$

$$A(s) = \sum_{k=0}^n a_k \cdot s^k \quad \text{and} \quad B(s) = \sum_{k=0}^n b_k \cdot s^k.$$